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Comparisons of Wind and Wave Models with GEOSAT: Final Report

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Foreword

On 18 December 1944 an unforecasted storm hit the U.S.Navy's Third Fleet off the Philippine Islands. When the storm passed, 790 men were dead, 146 aircraft were lost, and 3 ships were sunk. This episode demonstrates that accurate wind and wave forecasts should be of highest priority to the Navy in both war and peace.

Since only good models can give good forecasts, this report compared Navy models to both satellite observations and other models used worldwide. Although the Navy wave model worked well, the wind model may need improvement.

William B Moseley

W. B. Moseley
Technical Director

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Commanding Officer

Executive Summary

Analyses from the U.S. Navy's operational wind and wave models were compared to similar outputs from foreign and domestic agencies. Model outputs were ranked by agreement with satellite wind and wave observations for two days (10 March and 10 September 1986). The Navy's wave model ranked high on both days, but the Navy's wind model did not.

Acknowledgments

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A review of our preliminary report by Mr. R. M. Clancy of the Fleet Numerical Oceanography Center was most valuable in preparing this final report.

Contents

Comparisons of Wind and Wave Models with GEOSAT: Final Report

I. Introduction

Since winds and waves affect naval operations, models to analyze (depict present conditions) and forecast (depict future conditions) these variables are run routinely at the U.S. Navy's Fleet Numerical Oceanography Center. The operational wind model is described by Rosmond (1981), and the wave model is by Clancy et al. (1986).

In addition to this Navy effort, other domestic and foreign agencies also routinely run wind and wave models. Are their products any better? To find out, we compared the Navy's model analyses with those of other agencies.

This type of model ranking has previously been done. Cavaleri et al. (1982), for example, compared wave models driven with identical hypothetical winds. More recently, Canada's Atmospheric Environmental Service ranked several wind and wave models (including the Navy's) using moored wind-wave buoys for verification (Eid et al., 1986; Khandekar et al. 1986; Khandekar et al., 1986).

Conclusions from these earlier model comparisons, however, have limited applications to Navy needs. Model performance in hypothetical winds may not relate to performance in actual winds. Also, in the Canadian study, the reference buoys were all within 200 nm of the coast; therefore, the rankings applied to a nearshore area.

A better method for ranking large-scale wind and wave models became available when the Navy's GEOdesy SATellite (GEOSAT) was launched in 1985. This satellite, like the earlier GEOS-3 and SEASAT satellites, provides real-time, global coverage of surface wind speeds and significant wave heights. A description of its orbit and other properties, as well as data editing and matching techniques, are described in our earlier report (Pickett et al., 1986).

For this report, we applied our previous techniques to rank the Navy's wind and wave model performance for 10 March and 10 September 1986. The models were ranked against those of Canada (both military and civilian), the Netherlands, the Federal Republic of Germany, Japan, the U.S. Army, the National Oceanic and Atmospheric Administration (NOAA), and a private U.S. company (Offshore and Coastal Technology). Our results show that the Navy model rated highly on both days.

II. Method

A. Model Output

To obtain model output, we requested agencies to send us copies of their analyzed (not forecast) surface wind speed and significant wave height fields for 0000, 0600, 1200, 1800, and 2400 GMT on 10 March and 10 September 1986. Since we planned to compare their routine products, we did not ask for any special runs, grids, or levels.

B. Satellite Data

GEOSAT data are available within a few hours of being observed. They are transmitted to a ground station as the satellite passes over during each near-polar orbit. On board the satellite, a radar altimeter is used to provide the data for estimating ocean surface winds and wave heights.

Wind speeds are derived from the return pulse magnitude, since the pulse's energy is absorbed by wind-generated capillary waves and foam. Significant wave heights are estimated from the leading-edge slope of the return pulse, since high seas spread this pulse and reduce its slope. Algorithms to convert altimeter pulse magnitudes and slopes to wind speeds and wave heights were derived and improved in the earlier SEASAT and GEOS satellite experiments. More details on the satellite sensors are given in Kilgus et al.(1984).

An accuracy study of GEOSAT sensors was done by Shuhy et al. (1987). They examined GEOSAT overflights of NOAA's moored buoy network and computed differences in simultaneous wind speed and significant wave height readings. Their root-mean-square error of differences between buoy wind speeds (measured 10 m above the surface) and GEOSAT wind speeds was 1.5 m/sec for 276 pairs of observations. For significant wave heights, they found a root-mean-square error of 0.3 m for 332 observations. These values, which are surprisingly small, combine both the satellite and the buoy errors.

C. Comparisons

After editing the two days of GEOSAT data (to eliminate transmission errors, nearshore regions, islands, and ice), we averaged wind speeds and wave heights over 1-sec intervals (1024) values). This calculation gave us space averages of approximately 7 km by 7 km.

Next, we matched GEOSAT times and locations to model outputs. Ideally, we would have preferred all model results to be in the same format on the same grid. Then we could have compared the same points for each. However, since we were working with operational products tailored to user needs, we had to resort to samples using any points that matched.

To pick our samples, we selected GEOSAT wind and wave data that were within 1.5 hours of model verification times. If we were provided magnetic tapes, we computer scanned both the model values and the time-matched GEOSAT values to extract all pairs that were within 50 km of each other. If we were provided grid maps or contour charts, the process was more subjective. We plotted the time-matched GEOSAT data on top of the charts, and read off overlapping points.

Matching the wind fields presented another problem. As satellite-derived winds are from such a different technology, we did not attempt any corrections (height, stability, etc.) of GEOSAT or model surface wind fields. We simply compared the model surface winds as we received them to GEOSAT winds.

Because most of the model results were for the North Atlantic, we tested the global models in two ways. First, they were compared to each other over the entire world. Next, North Atlantic subsets were extracted and compared against North Atlantic models.

III. Results

A. Statistics

A summary of the wave model results is shown in Table 1 (units: meters), and a summary of the wind model results is shown in Table 2 (units: meters per second). Each entry covers two rows and lists the agency or country, the region (global or name of region), the day, the mean difference of the matched points (model minus GEOSAT), standard deviation of these differences, root-mean-square error, scatter index of agreement, and number of matched points (see Panofsky and Brier, 1965, and Willmott, 1981 for definitions).

B. Variability

Statistics in the tables are rounded to one decimal place to mask sampling variability. We established that the second decimal place was not significant by running two kinds of tests.

First, we ran the Navy wind and wave models against GEOSAT for four other days to estimate day-to-day variability. Next, we repeated the table calculations with a variety of space and time matching criteria. Both tests produced changes in the table statistics in the second decimal place. Hence, by rounding to one place, we attempted to show only significant changes.

C. Interpretation

In general, a low mean in the tables is desirable and shows that a model is unbiased. A low standard deviation is also important, and indicates that model highs and lows are in the proper place and are of the proper magnitude. Information in these two statistics can also be combined into a single number: the root-mean-square error. This value should also be small in a good model.

The scatter index is similar to the standard deviation. Whereas the standard deviation gives scatter about the mean, the scatter index gives scatter about a regression line through the data. Good models should have small scatter indexes.

Finally, the skill score and index of agreement are similar; both measure overall model–GEOSAT agreement. The higher the value, the better the agreement. Generally, skill scores are lower because randomness is removed during calculation.

D. Comparisons

We included all these statistics in the tables to allow comparisons with other results. For example, when Clancy et al. (1986) compared the Navy wave model to NOAA moored buoys, they used root-mean-square errors and scatter indexes. Their root-mean-square errors ranged from 0.7 to 1.3 m. In Table 1, our Navy global wave model root-mean-square errors are similar (0.9 and 1.1 m). Their scatter indexes were the same as ours (0.3 to 0.4). Apparently, comparisons with either buoys or satellites give comparable results.

As mentioned, the Navy models were also tested in Canada. These coastal North Atlantic tests (Khandekar et al., 1986) showed a root-mean-square error of 4.3 m/sec for the Navy wind model (we had 3.9 and 4.0 m/sec) and 2.0 m for the wave model (we had 0.6 and 0.8 m). We found smaller errors using the North Atlantic than they found using coastal data. This difference is probably because the coarse grid of the Navy's global model does not properly depict coastal regions.

E. Rankings

The results in Tables 1 and 2 are rearranged in Tables 3 and 4. Table 3 shows the 10 March 1986 model ranking based on three of the above indexes. Table 4 shows the same type ranking for September 1986. In both tables, models are grouped as regional (or a subset) and global.

IV. Conclusions

Our first conclusion is that the Navy wave model appears to work well. In spite of its simpler physics,

compared to newer models, no other model beat it consistently. Advantages of advanced physics were not evident in our tests.

The major region where the Navy wave model had problems was in the southern ocean. Figure 1 shows that most wave model errors occurred off Antarctica. They probably stemmed from poor wind input or poor ice edge locations (which gave wrong fetches).

Our second conclusion is that the Navy wind model may need improvement. As mentioned earlier, ranking wind models was more subjective because of the uncertainty associated with model and GEOSAT levels. Nevertheless, in both the Canadian study and in this study, the Navy wind model did not do as well as others.

Our final conclusion is that GEOSAT provides an ideal way to evaluate wind and wave models. In addition, its data could be injected directly into models. This combination of testing to find the best model and assimilating GEOSAT observations into that model should result in a significant leap in the accuracy of wind and wave data going out to the Fleet.

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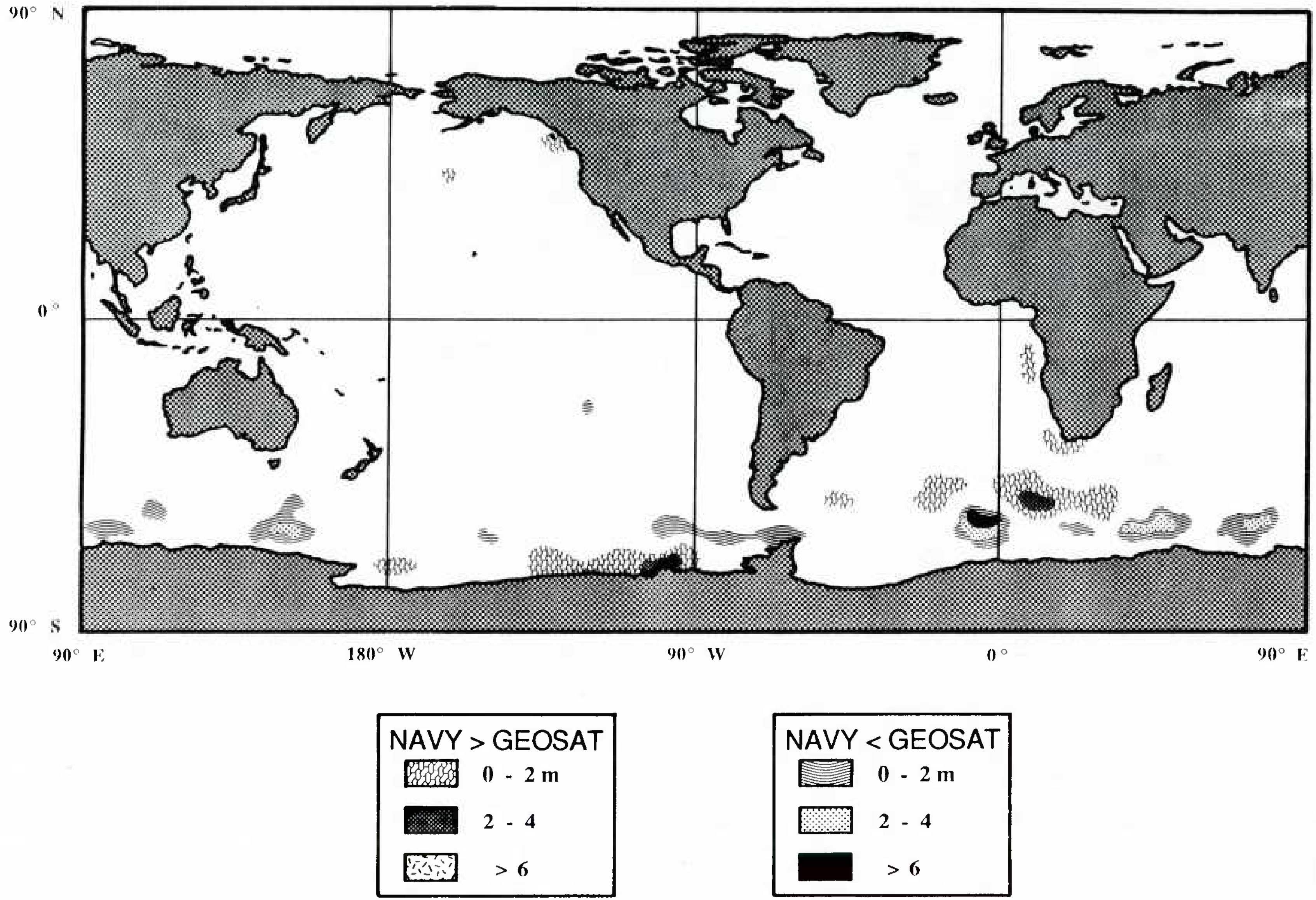

Figure 1. World chart showing areas of differences (in meters) between Navy wave model and GEOSAT on 10 September 1986.

Table 1. Statistics of differences between wave models and GEOSAT for two days.

MODEL & REGION	DATE	MEAN	STANDARD DEVIATION	RMS ERROR	SCATTER INDEX	SKILL SCORE	INDEX OF AGREEMENT	NUMBER OBS.	COMMENTS
CANADIAN 1	10 MAR 86	1.8 M	1.6 M	2.4 M	0.7	0.0	0.4	38	A
N. ATLANTIC	10 SEP 86								
CANADIAN 2	10 MAR 86	0.1	1.3	1.3	0.3	0.5	0.8	48	A
N. ATLANTIC	10 SEP 86								
CANADIAN MIL.	10 MAR 86	-0.2	1.5	1.5	0.4	0.3	0.6	67	A,I
N. ATLANTIC	10 SEP 86	0.5	1.0	1.2	0.6	0.3	0.7	115	A,I
FED. REP. GERMANY	10 MAR 86	0.5	0.8	0.9	0.3	0.3	0.8	135	B
N. ATLANTIC	10 SEP 86	-0.1	0.6	0.7	0.4	0.4	0.8	93	B
JAPANESE	10 MAR 86	0.3	0.4	0.5	0.3		0.6	14	A,C
S. OF JAPAN	10 SEP 86	0.1	0.4	0.4	0.4		0.3	13	A,C
NETHERLANDS	10 MAR 86	0.0	1.1	1.1	0.3	0.6	0.8	87	A
N. ATLANTIC	10 SEP 86	0.0	0.5	0.5	0.3	0.6	0.9	86	A
OCTI	10 MAR 86	-0.1	1.3	1.3	0.4	0.4	0.8	58	B,E,F
N. ATLANTIC	10 SEP 86	1.2	1.1	1.6	0.8	0.3	0.7	41	B,E,G
U.S. ARMY	10 MAR 86	-0.8	1.1	1.4	0.4	0.3	0.8	61	B,F,H
GLOBAL	10 SEP 86								
U.S. ARMY	10 MAR 86	-0.8	1.0	1.3	0.4	0.3	0.8	36	B,D,F
N. ATLANTIC	10 SEP 86								
U. S. NAVY	10 MAR 86	0.2	0.8	0.9	0.4	0.5	0.9	243	B
GLOBAL	10 SEP 86	-0.1	1.1	1.1	0.3	0.5	0.9	127	B
U.S. NAVY	10 MAR 86	0.4	0.7	0.8	0.3	0.6	0.9	81	B,D
N. ATLANTIC	10 SEP 86	0.1	0.6	0.6	0.3	0.6	0.9	48	B,D
U. S. NOAA	10 MAR 86	-0.1	0.9	0.9	0.3	0.3	0.7	393	A
GLOBAL	10 SEP 86	0.6	1.2	1.3	0.4	0.4	0.8	237	A
U. S. NOAA	10 MAR 86	-0.7	1.2	1.4	0.5	0.2	0.5	129	A,D
N. ATLANTIC	10 SEP 86	-0.2	0.6	0.6	0.3	0.4	0.9	40	A,D

Key to Comments:

A - Compared by hand from charts
B - Compared by computer from magnetic tape
C - Insufficient observations for skill score
D - Subset of global model
E - Run on desktop computer
F - Run with U.S. NOAA winds
G - Run with U.S. Navy winds
H - Northern hemisphere only
I - Hand drawn analysis

Table 2. Statistics of differences between wind models and GEOSAT for two days.

MODEL & REGION	DATE	MEAN	STANDARD DEVIATION	RMS ERROR	SCATTER INDEX	SKILL SCORE	INDEX OF AGREEMENT	NUMBER OBS.	COMMENTS
CANADIAN 1	10 MAR 86	1.1 M/S	3.4 M/S	3.5 M/S	0.4	0.3	0.7	47	A
N. ATLANTIC	10 SEP 86								
CANADIAN 2	10 MAR 86	0.2	3.1	3.0	0.3	0.3	0.8	48	A
N. ATLANTIC	10 SEP 86	0.3	2.4	2.3	0.3		0.8	13	B,C
FED REP GERMANY	10 MAR 86	0.9	2.8	3.0	0.4	0.4	0.8	135	B
N. ATLANTIC	10 SEP 86	-1.6	3.3	3.6	0.5	0.2	0.6	93	B
JAPANESE	10 MAR 86	1.0	2.4	2.5	0.4		0.5	14	A,C
S. OF JAPAN	10 SEP 86	0.3	1.3	1.3	0.2		0.6	10	A,C
NETHERLANDS	10 MAR 86	2.2	2.8	3.5	0.5	0.2	0.8	87	A
N. ATLANTIC	10 SEP 86	0.4	2.7	2.7	0.4	0.4	0.8	63	A
U. S. NAVY	10 MAR 86	1.1	3.9	4.1	0.6	0.3	0.7	138	B
GLOBAL	10 SEP 86	0.2	3.8	3.8	0.4	0.3	0.7	131	B
U.S. NAVY	10 MAR 86	1.7	3.6	4.0	0.5	0.3	0.7	66	B,D
N. ATLANTIC	10 SEP 86	-0.9	3.8	3.9	0.6	0.1	0.6	49	B,D
U. S. NOAA	10 MAR 86	-1.1	2.8	2.9	0.4	0.5	0.8	74	A
GLOBAL	10 SEP 86	-1.4	3.4	3.6	0.4	0.4	0.7	129	B
U. S. NOAA	10 MAR 86	0.1	3.1	3.1	0.4	0.3	0.7	71	A,D
N. ATLANTIC	10 SEP 86	-1.2	1.5	1.9	0.3	0.5	0.9	26	B,D

Key to Comments:

A - Compared by hand from charts
B - Compared by computer from magnetic tape
C - Insufficient observations for skill score
D - Subset of global model
E - Run on desktop computer
F - Run with U.S. NOAA winds
G - Run with U.S. Navy winds
H - Northern hemisphere only
I - Hand drawn analysis

Table 3. Model ranking based on GEOSAT agreement on 10 March 1986. Brackets indicate ties. Models with less than 25 observations were not included.

Rank by Skill Score	Rank by Index of Agreement	Rank by Root Mean Square Error
	Regional Wave Models	
Netherlands	U.S. Navy	U.S. Navy
U.S. Navy	U.S. Army	Fed. Rep. Germany
Canadian	Canadian 2	Netherlands
OCTI	OCTI	Canadian 2
U.S. Army	Netherlands	OCTI
Canadian Military	Fed. Rep. Germany	U.S. Army
Fed. Rep. Germany	Canadian Military	U.S. NOAA
U.S. NOAA	U.S. NOAA	Canadian Military
Canadian I	Canadian I	Canadian I
	Global Wave Models	
U.S. Navy	U.S. Navy	U.S. Navy
U.S. NOAA	U.S. Army	U.S. NOAA
U.S. Army	U.S. NOAA	U.S. Army
	Regional Wind Models	
Fed. Rep. Germany	Fed. Rep. Germany	Fed. Rep. Germany
Canadian I	Netherlands	Canadian 2
Canadian 2	Canadian 2	U.S. NOAA
U.S. Navy	Canadian 1	Canadian I
U.S. NOAA	U.S. Navy	Netherlands
Netherlands	U.S. NOAA	U.S. Navy
	Global Wind Models	
U.S. NOAA	U.S. NOAA	U.S. NOAA
U.S. Navy	U.S. Navy	U.S. Navy

Table 4. Model ranking based on GEOSAT agreement for 10 Sept. 1986. Brackets indicate ties. Models with less than 25 observations were not included.

Rank by Skill Score	Rank by Index of Agreement	Rank by Root Mean Square Error
	Regional Wave Models	
U.S. Navy	U.S. Navy	Netherlands
Netherlands	Netherlands	U.S. Navy
Fed. Rep. Germany	U.S. NOAA	U.S. NOAA
U.S. NOAA	Fed. Rep. Germany	Fed. Rep. Germany
OCTI	Canadian Military	Canadian Military
Canadian Military	OCTI	OCTI
	Global Wave Models	
U.S. Navy	U.S. Navy	U.S. Navy
U.S. NOAA	U.S. NOAA	U.S. NOAA
	Regional Wind Models	
U.S. NOAA	U.S. NOAA	U.S. NOAA
Netherlands	Netherlands	Netherlands
Fed. Rep. Germany	Fed. Rep. Germany	Fed. Rep. Germany
U.S. Navy	U.S. Navy	U.S. Navy
	Global Wind Models	
U.S. NOAA	U.S. NOAA	U.S. NOAA
U.S. Navy	U.S. Navy	U.S. Navy